Spectral Modeling, Unification, and Cosmological Evolution of Blazars

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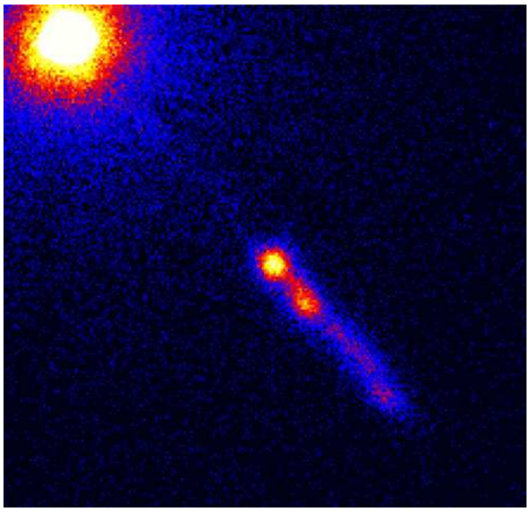
1) Overview: Phenomenology and spectra of blazars

2) Spectral modeling of blazars

3) Unification and cosmological evolution

1) Overview: Phenomenology and spectra of blazars

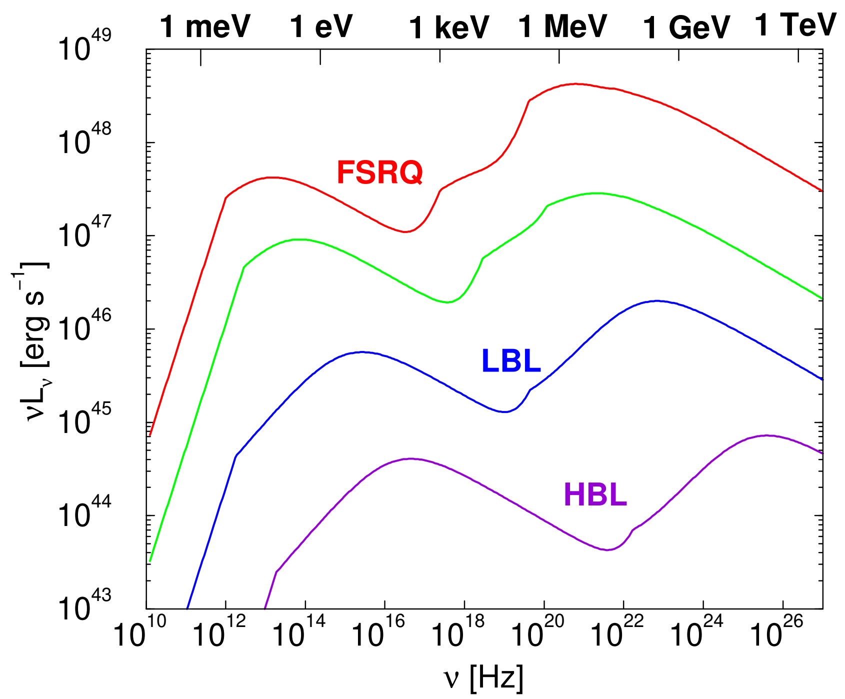
Blazars = class of active galaxies consisting of
BL Lac objects and
γ-ray loud qu**asars**



a) General characteristics:

- Emit much (most) of their total luminosity in γ-rays
- Rapidly variable at all wavelengths, on timescales down to $\lesssim$1 hr
- Linear polarization in radio and optical emission
- One-sided jets (resolvable in radio, optical, X-rays)
- Apparent superluminal motion, up to $v_{\rm app} \sim 20$ c

b) Blazar spectra:



Sequence HBL $\longrightarrow$ LBL $\longrightarrow$ FSRQ:

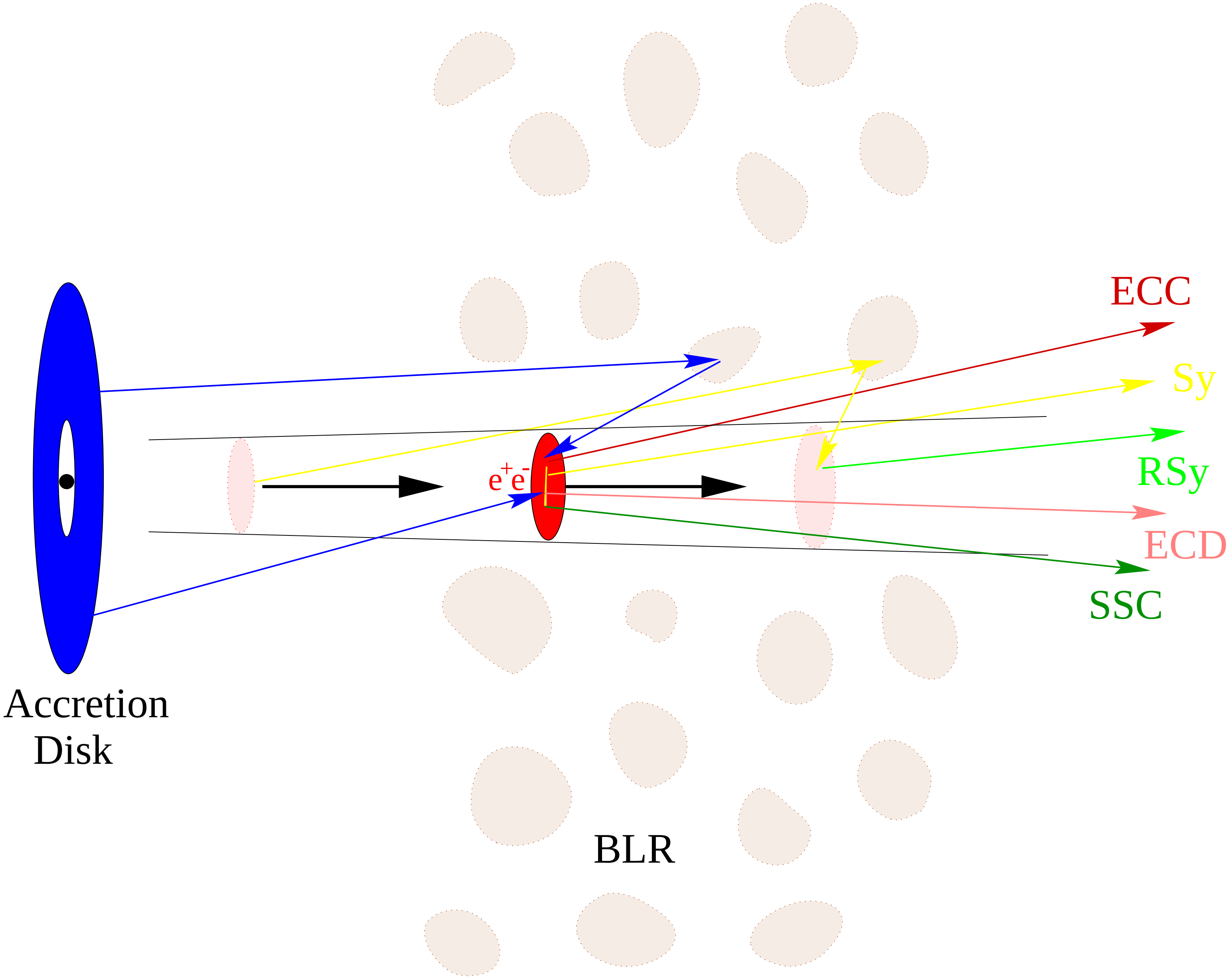
- increasing apparent bolometric luminosity
- decreasing νF_ν spectral peak energies
- increasing dominance of γ-ray emission (during flares)

2) Spectral modeling of blazars

(based on leptonic jet models)

General assumptions:

- Relativistic outflow from a supermassive black hole in the center of the galaxy
- Electrons and/or pairs are accelerated to ultrarelativistic energies at a relativistic shock front and/or at the base of the jet
- Electrons/pairs are accelerated to a power-law distribution in energy (with low-energy cutoff or break)
- Electrons/pairs radiate via
  — synchrotron radiation
  — Comptonization of self-generated synchrotron radiation (SSC)
  — Comptonization of external radiation (ECD/ECC/RSy)
- Electrons/pairs cool via the above radiation mechanisms (and possibly adiabatic cooling)
- Possibly: re-injection of pairs due to pair production; re-acceleration of pairs by Fermi acceleration

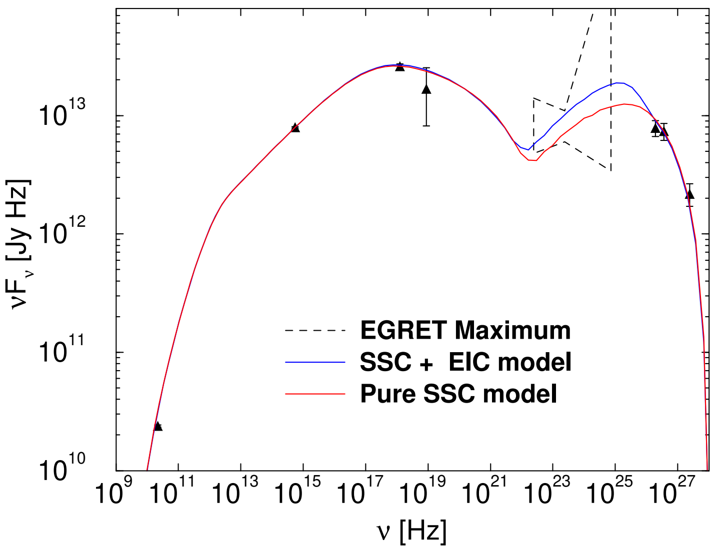


Blazar Evolution

Examples:

Mrk 501 (HBL)

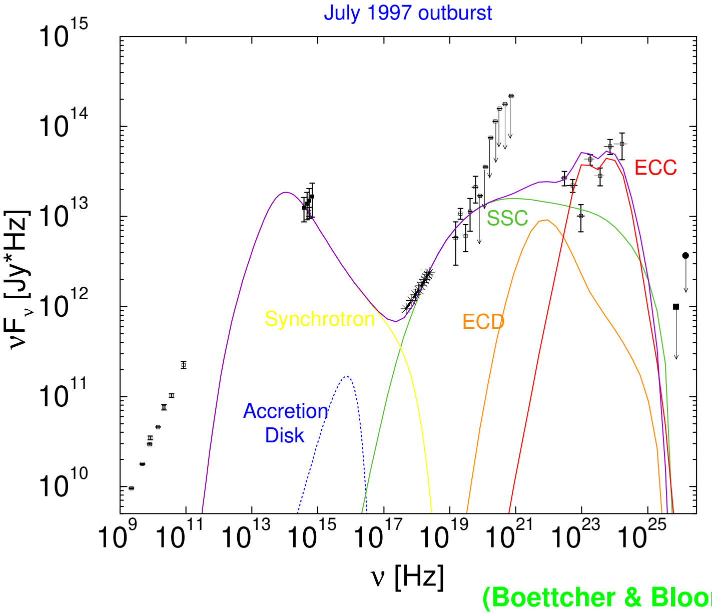
MJD 50564.566



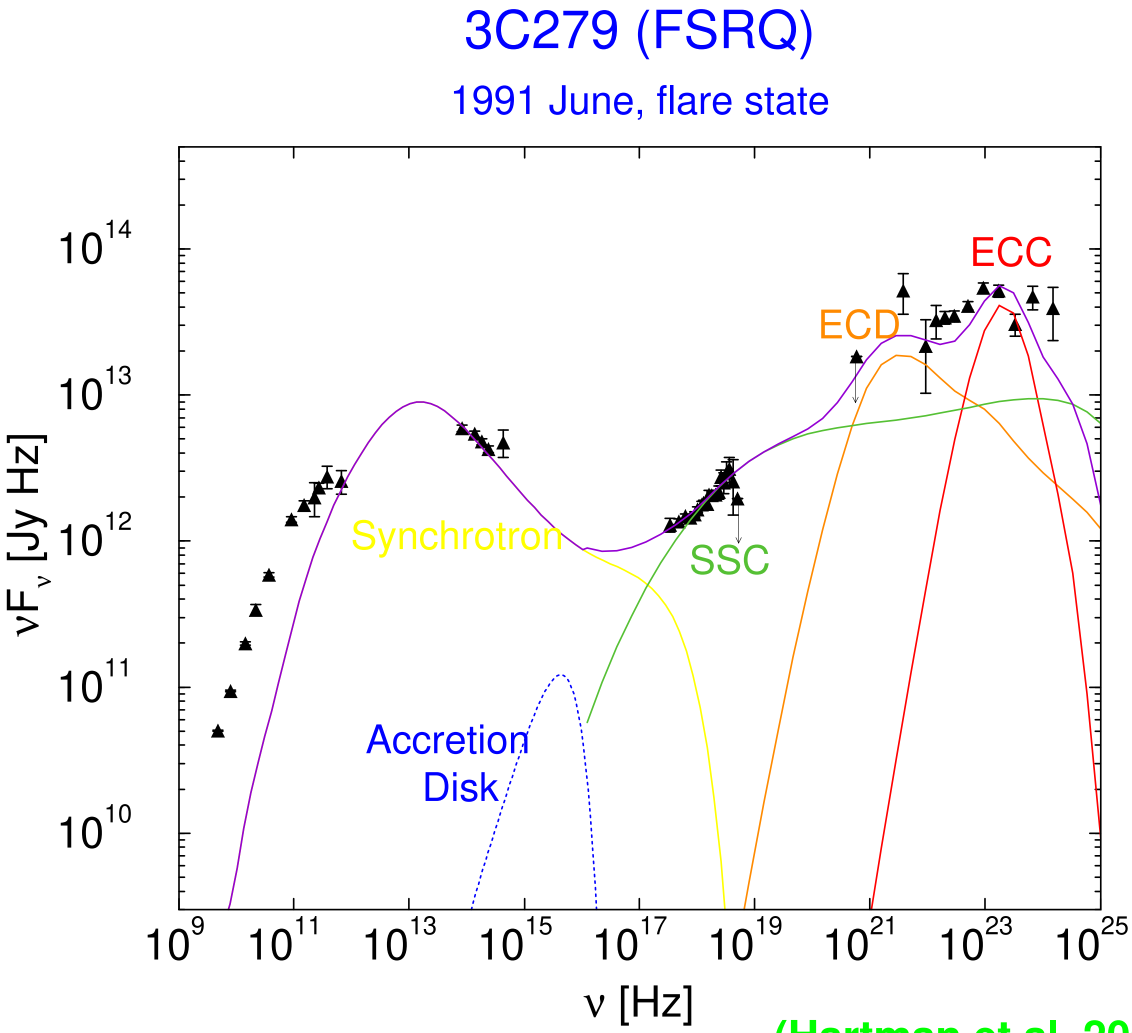
(Petry et al. 2000)

BL Lacertae (LBL)

July 1997 outburst



(Boettcher & Bloom 2000)



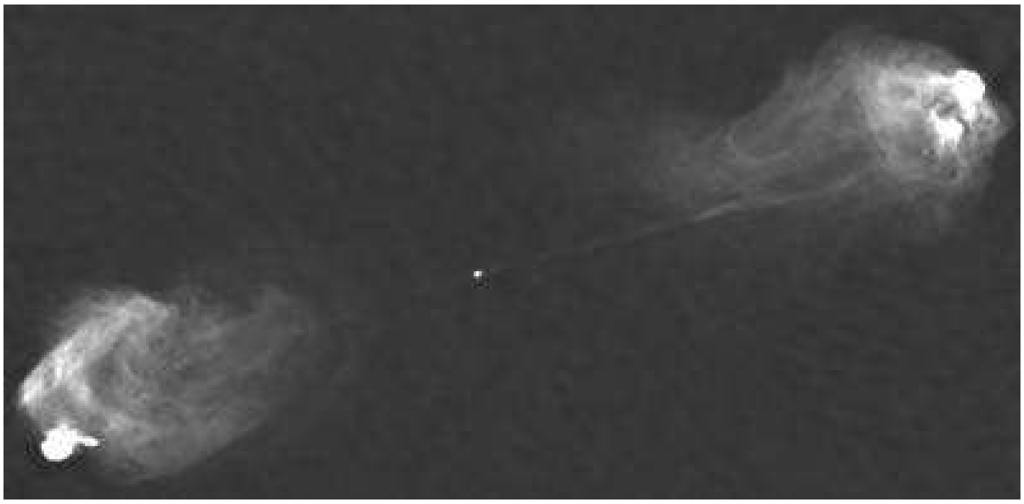
(Hartman et al. 2001)

Spectral Modeling of FSRQs vs. BL Lacs

The sequence HBL $\longrightarrow$ LBL $\longrightarrow$ FSRQ
is consistent with external-radiation Comptonization
becoming more dominant at γ-ray energies
(Ghisellini et al. 1998)

- HBLs are consistent with pure SSC models
- LBLs (e.g. BL Lacertae) require a moderate contribution of external Comptonization
- FSRQs are better fit by external-Comptonization dominating the γ-ray emission and electron cooling (SSC dominating hard X-rays), at least during γ-ray flares

3) Blazar unification and cosmological evolution



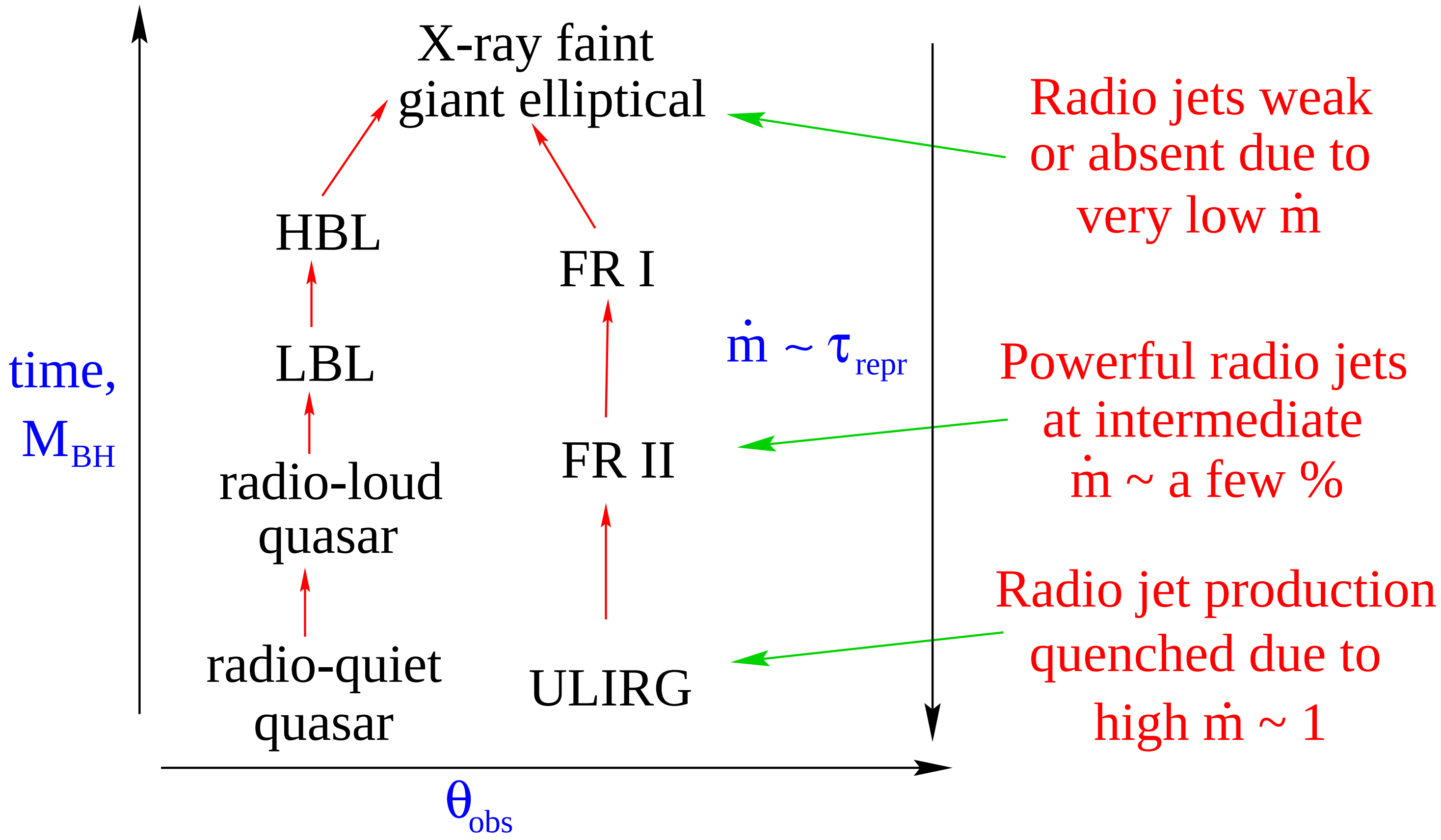
Well-known: Unification of AGNs based on viewing-angle effects

Radio quasars $\longleftrightarrow$ FR II radio galaxies

BL Lac objects $\longleftrightarrow$ FR I radio galaxies

Blazars are radio galaxies oriented with their jets pointing towards Earth.

Evolutionary scenario for unification between blazar sub-classes and between FR Is and FR II radio galaxies



Evolutionary stages of blazars and radio galaxies

- Early phase of black-hole growth:

  High accretion rate; jet production quenched due to $\dot{m} \sim 1$; high density of circumnuclear material $\Longrightarrow$ strong optical emission lines, but weak or no radio jets; no high-energy γ-ray production

- Quasar / FR II phase:

  Moderately high accretion rate; high density of circumnuclear material $\Longrightarrow$ strong optical emission lines; powerful radio jets; powerful γ-ray production beamed along jet axis; strong external-Compton cooling; low νF_ν peak energies

- BL Lac / FR I phase:

  Moderately low accretion rate; low density of circumnuclear material $\Longrightarrow$ weak or no optical emission lines; less powerful radio jets; external-Compton emission and cooling negligible; high νF_ν peak energies

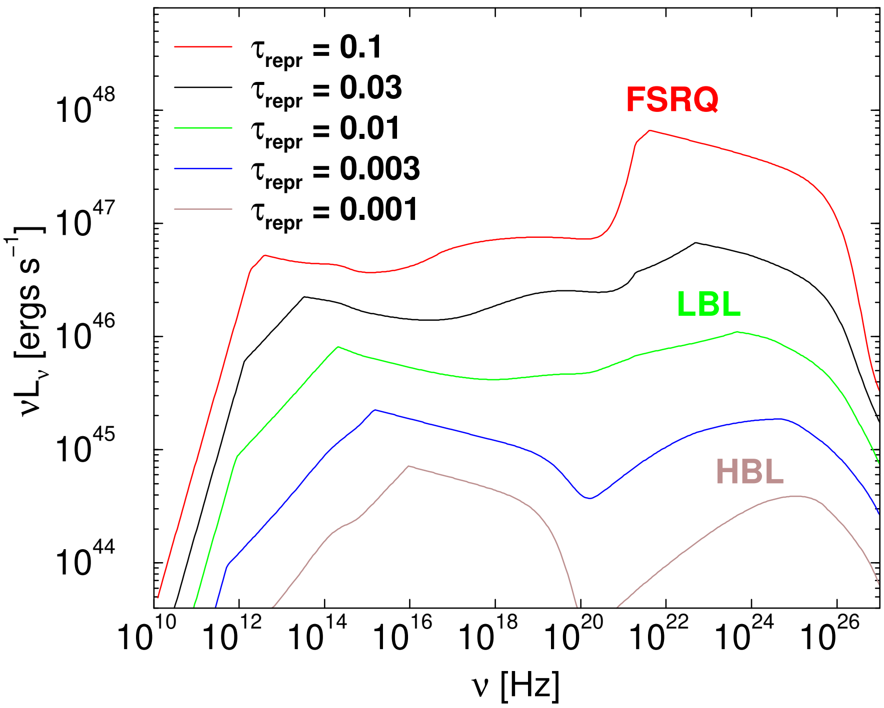
- "dead blazar" phase (X-ray faint giant ellipticals):

  very low accretion rate; very low density of circumnuclear material $\Longrightarrow$ inactive galactic nucleus; X-ray faintness due to dominance of radiatively inefficient mode of accretion (ADAF/CDAF/ADIOS?)

Spectral modeling of blazar evolution

Quasi-analytical model for blazar spectra:

- Injection of power-law electron distribution into the jet
- Determine balance between injection and radiative cooling and escape
- Include synchrotron, SSC, external-Compton
- Assume: Accretion-disk luminosity $\propto$ optical depth of reprocessing circumnuclear material $\propto$ jet power



Summary

- Observed sequence of spectral properties: FSRQ → LBL → HBL
- Can be explained in terms of a decreasing importance of external radiation field to Compton scattering off relativistic electrons in a relativistic jet
- Evolutionary scenario: Gradual depletion of circumnuclear environment by accretion onto supermassive black hole
- This unifies radio-loud AGN with radio-quiet quasars and ULIRGs (high $\dot{m}$) and X-ray faint giant ellipticals (very low $\dot{m}$).
- Consistent with:
  - → observed positive cosmological evolution in quasars vs. slightly negative cosmological evolution in BL Lacs
  - → distribution of central black-hole masses in non-active ellipticals extending beyond those of AGNs
  - → observed anti-correlation of soft X-ray flux with radio and hard X-ray flux in some Galactic X-ray binaries; in agreement with theoretical models linking the existence of an ADAF/ADIOS to the production of radio jets